Value of Lifestyle Intervention to Prevent Diabetes and Sequelae

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Background: The Community Preventive Services Task Force recommends combined diet and physical activity promotion programs for people at increased risk of type 2 diabetes, as evidence continues to show that intensive lifestyle interventions are effective for overweight individuals with prediabetes.

Purpose: To illustrate the potential clinical and economic benefits of treating prediabetes with lifestyle intervention to prevent or delay onset of type 2 diabetes and sequelae.

Methods: This 2014 analysis used a Markov model to simulate disease onset, medical expenditures, economic outcomes, mortality, and quality of life for a nationally representative sample with prediabetes from the 2003–2010 National Health and Nutrition Examination Survey. Modeled scenarios used 10-year follow-up results from the lifestyle arm of the Diabetes Prevention Program and Outcomes Study versus simulated natural history of disease.

Results: Over 10 years, estimated average cumulative gross economic benefits of treating patients who met diabetes screening criteria recommended by the ADA ($26,800) or USPSTF ($24,700) exceeded average benefits from treating the entire prediabetes population ($17,800). Estimated cumulative, gross medical savings for these three populations averaged $10,400, $11,200, and $6,300, respectively. Published estimates suggest that opportunistic screening for prediabetes is inexpensive, and lifestyle intervention similar to the Diabetes Prevention Program can be achieved for $\leq$$2,300 over 10 years.

Conclusions: Lifestyle intervention among people with prediabetes produces long-term societal benefits that exceed anticipated intervention costs, especially among prediabetes patients that meet the ADA and USPSTF screening guidelines.

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Introduction

Approximately 86 million people in the U.S. have prediabetes, a condition where blood glucose levels are elevated but remain below the diabetic threshold.[1] These individuals are at high risk for developing type 2 diabetes, heart disease, and stroke, with estimated annual diabetes incidence rates ranging from 1% to 2%[2,3] for the entire prediabetes population to 5% to 7%[2,4,5] among high-risk populations.

Clinical trials demonstrate that counseling and treatment can prevent diabetes or delay onset among high-risk populations.[6–9] Lifestyle intervention in the Diabetes Prevention Program and Outcomes Study (DPPOS) resulted in reduced body weight and hemoglobin A1c (HbA1c) levels that persisted through 10-year follow-up.[7]

Screening for diabetes and prediabetes and subsequent diagnosis are precursors to receiving counseling and treatment. The American Diabetes Association (ADA) recommends screening overweight, asymptomatic adults with additional risk factors, and triennial screening for adults aged $\geq$45 years without risk factors.[10] The U.S. Preventive Services Task Force (USPSTF) 2008 guidelines recommend screening asymptomatic adults with sustained hypertension, though draft new screening

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guidelines from USPSTF are similar to the ADA guidelines.[11] ADA recommends screening for prediabetes; USPSTF (2008 guidelines) does not, citing limited evidence on long-term benefits. Limited information exists on screening cost effectiveness, although one study concluded that prediabetes and diabetes screening and subsequent intervention appear cost effective.[3] This study estimates the potential long-term health and economic benefits of lifestyle intervention among the total U.S. prediabetes population and subsets meeting ADA and USPSTF screening criteria.

Methods

This 2014 analysis used a Markov-based microsimulation model similar to those previously used to study health outcomes.[12,13] The approach simulated interactions between demographics; smoking status; biometrics—BMI, systolic (SBP) and diastolic blood pressure (DBP), total cholesterol, high-density lipoprotein cholesterol, and HbA1c levels; incidence of disease and adverse health events; and mortality (Figure 1). Health outcomes impacted annual medical costs, productivity (employment status, missed work days, income, and disability payments), and quality of life. Modeled scenarios used 10-year follow-up results from the lifestyle arm of the DPPOS versus simulated natural disease history.[14]

The analyzed population, statistical analysis, and predictive equations are briefly described in the following sections. The Appendix (available online) provides additional detail on model design, data, assumptions, methods, and validation, following guidelines published by the International Society for Pharmacoeconomics and Outcomes Research and Society for Medical Decision Making.[15]

Study Population

The National Health and Nutrition Examination Survey (NHANES) is a nationally representative sample of the non-institutionalized population.[16] The combined 2003–2010 NHANES contains 3,700 adults with prediabetes defined by $6.4\% \geq \text{HbA1c} \geq 5.7\%$.[10] Although other diagnostic tests (fasting plasma glucose [FPG] and 2-hour oral glucose tolerance test [OGTT]) can be used to determine prediabetes status, HbA1c was used to model diabetes onset and is a risk factor in published comorbidity prediction equations. Sensitivity analyses used both

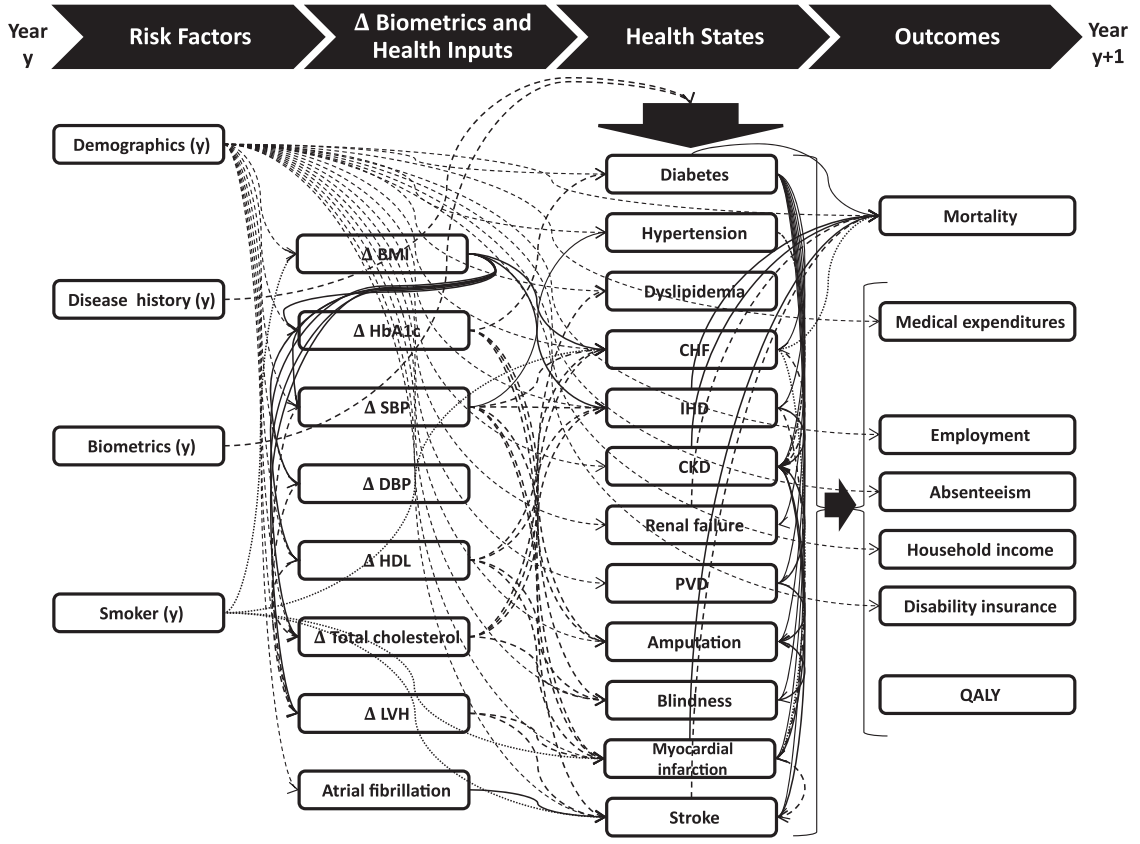

Figure 1. Disease Prevention Microsimulation Model Overview.

Note: Arrows indicate linkages in the model. Risk factors (especially aging) affect annual change in biometrics. Risk factors (including biometrics) are used to model disease incidence. Presence of disease, and other factors such as demographics, affects mortality risk, medical expenditures, and the economic outcomes modeled. See Appendix (available online) for more detail on the model.

CHF, congestive heart failure; CKD, chronic kidney disease; DBP, diastolic blood pressure; HbA1c, hemoglobin A1c; HDL, high-density lipoprotein; IHD, ischemic heart disease; LVH, left ventricular hypertrophy; PVD, peripheral vascular disease; QALY, quality-adjusted life year; SBP, systolic blood pressure.

HbA1c and FPG to identify the prediabetes population and model diabetes onset.

Individual profiles contained demographics (age, sex, race, and Hispanic ethnicity), biometrics, current smoking status, and presence of recognized risk factors and complications of diabetes—hypertension, ischemic heart disease, congestive heart failure, stroke, heart attack, renal failure, amputation, and blindness.[17–19] This profile created a starting point for simulating future health outcomes.

Intervention and nonintervention scenarios were simulated for three prediabetes populations: (1) all adults (n=3,700); (2) adults satisfying ADA screening criteria (n=2,887)[10]; and (3) adults satisfying USPSTF (2008 guidelines) screening criteria (n=1,621).[11] Each simulation used 100,000 observations where sample weights determined the probability a person was drawn from the NHANES sample.

Simulating Health Outcomes, Mortality, and Quality of Life

Each person's current characteristics were used to predict next year's health outcomes, with this process repeated through 10 years or death. The intervention scenario assumed average HbA1c and body weight declines observed during the DPPOS 10-year follow-up; the nonintervention scenario assumed the natural history of disease under current standards of care.[14] Model parameters and prediction equations came from the United Kingdom Prospective Diabetes Study (UKPDS),[19–23] Framingham Heart Study,[24–28] and published trials and observational studies. Original research with NHANES filled in data gaps (Appendix, available online).

Illustrating interdependence of clinical and disease outcomes, the following sequence modeled annual change in risk factors and outcomes:

1. Body weight changed with age. The rate of change reflected the average difference in BMI between subsequent ages in a cross-sectional analysis of NHANES data, calculated separately by sex and body weight category ($BMI < 25$, $25 \le BMI < 30$, $BMI \ge 30$). Validation found patterns similar to published findings using longitudinal data.[29]
2. For people experiencing diabetes onset, rates of change in SBP, HbA1c, and cholesterol were predicted using demographics and BMI change with equations from the UKPDS Outcomes Model.[19] For people with prediabetes, annual changes in SBP, DBP, total cholesterol, and high-density lipoprotein cholesterol were modeled based on age and change in BMI. Annual change in HbA1c was modeled based on age, BMI change, and total cholesterol. The equations combined analysis of NHANES and parameters from the literature.[24,30,31] A meta-analysis of clinical trials found that a 1-kg loss in excess body weight is associated with a 1.05-mmHg reduction in SBP.[30] To estimate age-associated SBP changes, ordinary least squares regression with NHANES data (separately for men and women) used SBP as the dependent variable, age and age squared as explanatory variables, and BMI as a control variable.
3. Onset of diabetes and hypertension were modeled from HbA1c[32] and SBP levels,[33] respectively, using clinical guidelines.
4. Equations to predict incidence of atrial fibrillation[20,21]; left ventricular hypertrophy[34]; ischemic heart disease (IHD), myocardial infarction (MI), congestive heart failure (CHF), and stroke[19,22,25]; chronic kidney disease (CKD)[23]; and peripheral vascular disease[35] came from the literature for the prediabetes population. For the diabetes population, the equations for many of these conditions and amputation and blindness came from the UKPDS Outcomes Model.[19]
5. Annual, event-based mortality rates for diabetes,[19] IHD,[22] CHF,[36] MI,[37] stroke,[38] renal failure,[23] and CKD[39] came from published equations and reflect mortality risk associated with demographics, biometrics, smoking, and disease presence. All-cause mortality rates were adjusted to remove cause-specific mortality modeled separately.[40]
6. Estimates of reduced quality of life associated with obesity, amputation, and renal failure were based on people with type 2 diabetes, whereas estimates for other conditions were based on a nationally representative sample of adults.[41,42]

Simulating Medical Expenditures and Economic Outcomes

All monetary estimates are in 2013 U.S. dollars and reflect present values using a 3% discount rate. The relationship between annual medical expenditures and patient characteristics was estimated using a generalized linear model with gamma distribution and log link, analyzing data from the 2006–2010 files (n=165,913) of the Medical Expenditure Panel Survey (MEPS). Explanatory variables were age group, sex, race, Hispanic ethnicity, insurance status, body weight (overweight, obese), presence of modeled diseases, and interaction terms for diabetes and modeled diseases (regression results shown in Appendix Exhibit 27, available online). Estimates based on MEPS reflect average annual costs for those living. End of life costs were based on published estimates.[43]

Estimated relationships between disease presence and economic outcomes came from regression analysis of the linked 2008–2010 MEPS and National Health Interview Survey files. Explanatory variables were the same as those described here. Economic outcomes analyzed for the entire adult population in the linked files were employed status (n=25,296) and receiving Supplemental Security Income for disability (n=26,080)—both estimated with logistic regression. Annual missed workdays were analyzed for the employed population (n=18,699) using negative binomial regression. Ordinary least squares regression with MEPS data (n=165,913) modeled household income (regression results presented in Appendix Exhibit 28, available online).

Results

The simulated sample is nationally representative of the prediabetic population identifiable using HbA1c. In the initial simulation year, 51% were women, and mean ages were 54 years for men and 58 years for women (Table 1). Those meeting USPSTF (2008 guidelines) criteria were older, with higher BMI, and had greater prevalence of cardiovascular disease relative to those meeting ADA criteria and the total prediabetic population.

Under the nonintervention scenario, nearly one third of the prediabetes population (32.5%) developed diabetes within 10 years (Table 2). Mortality reached 33.9%, and

Table 1. Prediabetes Population Starting Year Characteristics

	All prediabetes		ADA identified		USPSTF (2008) identified	
	Men	Women	Men	Women	Men	Women
%	49.2	50.8	49.7	50.3	46.1	53.9
Mean						
Age, y	53.9	58.1	55.0	58.9	59.3	63.4
BMI	30.0	30.1	31.0	31.5	31.3	30.9
Systolic blood pressure, mmHg	128.1	129.7	128.3	130.6	132.6	136.8
Diastolic blood pressure, mmHg	73.6	69.7	73.8	69.8	74.1	69.6
Cholesterol ratio	4.7	4.0	4.8	4.1	4.6	4.0
HbA1c, %	5.9	5.9	5.9	5.9	5.9	5.9
Disease prevalence, %						
Congestive heart failure	3.4	2.3	4.3	2.7	6.3	4.3
History of myocardial infarction	7.3	2.9	9.2	3.3	12.1	4.9
History of stroke	3.3	4.4	3.7	4.7	6.5	7.5
Hypertension	50.7	55.1	40.8	38.9	100.0	100.0
Ischemic heart disease	11.2	6.6	14.0	7.9	19.2	11.8
Obesity	43.1	44.3	48.3	47.9	51.1	47.4

Note: Several risk factors and health states in the model are not available in the NHANES data used to create the starting year health profile. These conditions are modeled based on other patient characteristics—with some conditions modeled only among the population with simulated diabetes onset. Modeled conditions include amputation, atrial fibrillation, diabetic retinopathy, left ventricular hypertrophy, peripheral vascular disease, and renal failure (to include chronic kidney disease and end stage renal disease).
ADA, American Diabetes Association; HbA1c, hemoglobin A1c; NHANES, National Health and Nutrition Examination Survey; USPSTF, U.S. Preventive Services Task Force.

diabetes prevalence among those surviving at year 10 reached 36.4%. Over 10 years, 15.7% developed CKD, 13.8% developed CHF, and 10.7% developed IHD. The present value of gross medical expenditures over 10 years averaged $73,900 per person ($90,200 per person living at year 10).

Over 10 years, intervention reduced diabetes onset by 41%, CHF by 33%, IHD by 22%, and mortality by 20% (Table 3). Cumulative medical expenditures per person were $6,300 (9%) lower. Average nonmedical benefits were $11,500 higher—primarily from increased employment and household income. Absenteeism per worker declined, but higher employment increased total missed workdays. The present value of gross economic benefits of intervention averaged $17,800 ($16,100 using a 5% discount rate, $21,000 using a 0% discount rate).

Among the prediabetes population, approximately 43% had undetected prediabetes but met ADA criteria for diabetes screening, and 30% had undetected prediabetes but met USPSTF criteria in 2010.[44] Applied to the 2012 estimate of 86 million with prediabetes, this suggests that potentially 26–37 million case patients in 2012 could have been detected and enrolled in treatment. Without intervention, simulated diabetes onset over 10 years was 46.4% for the ADA-identified population and 44.3% for the USPSTF-identified population. Intervention reduced average, 10-year cumulative medical costs for the ADA-identified population by $10,400 ($12,000–$9,500 using a 0%–5% discount rate) and for the USPSTF-identified population by $11,200 ($12,800–$10,200) (Table 4).

If estimated benefits were scaled to the entire prediabetes population, these findings suggest that, over 10 years, the nation could potentially prevent more than 11.4 million cases of diabetes, avoid $539 billion in medical costs, create $992 billion in nonmedical benefits (largely through 11 million additional years of employment), and gain nearly 30 million quality-adjusted life years. Among the 37 million people with undiagnosed prediabetes meeting ADA screening guidelines, intervention could prevent 9.5 million diabetes cases with economic benefits of $991 billion.

A formal cost effectiveness analysis was outside the scope of this study, but others have reported costs for screening and treatment.[45–47] The Healthy Living Partnerships to Prevent Diabetes (HELP PD) trial, which

Table 2. Cumulative Outcomes for Nationally Representative Sample of 100,000 Adults with Prediabetes (No Intervention Scenario)

	2 Years	5 Years	10 Years
New disease cases, *n*			
Diabetes	7,100	16,900	32,500
Ischemic heart disease	1,900	5,100	10,700
Congestive heart failure	2,600	6,700	13,800
Stroke	1,700	4,500	9,300
Heart attack	1,000	2,700	5,900
Renal failure	3,400	8,300	15,700
Amputation	10	50	140
Blindness	50	340	1,200
Medical expenditures ($ millions)	1,521	3,869	7,389
Medical expenditures/person still living	15,700	42,200	90,200
Nonmedical economic outcomes ($ millions)	8,763	19,489	31,909
Household income ($ millions)	9,137	20,346	33,372
Years of employment	104,850	243,210	421,810
Absenteeism (missed work days)	1,555,000	3,630,000	6,365,000
Absenteeism productivity loss ($ millions)	289	649	1,078
Supplemental Security Income ($ millions)	85	207	385
Mortality	5,000	14,800	33,900
Years of life	193,200	459,400	828,100
Quality-adjusted life years	150,430	353,960	628,450

Note: All dollar figures are present values in 2013 dollars, using a 3% discount rate. Numbers might not sum to totals because of rounding.

adapted the DPP approach to community-based settings, reported costs of $7.50 (2013 dollars) per test and 2.5 people screened for each identified prediabetes case.[46] Opportunistic screening for prediabetes is relatively inexpensive per person, although follow-up visits for confirmation and testing would increase detection costs.

DPP lifestyle intervention cost $3,770 (2013 dollars) per participant.[47] Subsequent lifestyle interventions have achieved similar outcomes at lower treatment cost through a different mix of medical and allied health professionals, use of electronic media, and a less-individualized approach. HELP PD costs were $850 per participant over 2 years, including the costs for counselor time, distribution of materials, a monthly newsletter, and reminder calls and e-mails. Cost was $568 during the intensive phase (Months 1–6), and $282 during the maintenance phase (Months 7–24). Over 10 years (with a 3% discount rate and attrition due to mortality), the cost would be $2,300 per participant. The YMCA's Diabetes Prevention Program achieved short-term patient weight loss results similar to HELP PD and the original DPP study, but at service-delivery costs of about $400 per person completing the 12-month program.[45]

Discussion

Lifestyle intervention among adults with prediabetes can reduce body weight, BP, and glycemic levels,[6,45,47] although clinical trials of treatment for prediabetes and early diabetes stages have produced disappointing results regarding impact on long-term complications.[5,48] Evidence suggests that lifestyle interventions implemented over a short period can still have long-lasting, beneficial, carryover effects on type 2 diabetes incidence.[49] Long-term health benefits are considered the true measure of diabetes screening program cost effectiveness.[50] Although other studies have reported the clinical benefits of lifestyle intervention, the primary contribution of this study is translating improvement in body weight and glycemic levels into estimates of long-term economic outcomes. There are three key implications of this study.

First, the simulated economic benefits of treating prediabetes via lifestyle intervention appear to far outweigh intervention costs over the analyzed 10-year period, with higher simulated benefits among the prediabetes population meeting ADA and USPSTF screening guidelines. Published estimates of opportunistic screening costs ($18.50) and intervention costs (about $2,300) are well below the simulated medical savings ($6,300–$11,200) and total societal benefits ($17,800–$26,800) per participant.

Second, the prediabetes population meeting ADA screening guidelines is younger and healthier than the population meeting USPSTF (2008) guidelines. Over 10 years, average medical savings from intervention were greater among the USPSTF population, but societal economic benefits were greater among the ADA population. In 2010, approximately 14.9 million people with undetected prediabetes met ADA, but not USPSTF, diabetes screening criteria, while 5.4 million met USPSTF, but not ADA, criteria.[44] Preliminary analysis of USPSTF's new draft screening guidelines suggest that the population detected with prediabetes is slightly larger than the population detected under the ADA

Table 3. Cumulative Benefits of Lifestyle Intervention for Nationally Representative Sample of 100,000 Adults with Prediabetes

	Cumulative impact			
	2 Years	5 Years	10 Years	Impact at year 10, %
New disease cases, *n*				
Diabetes	(2,800)	(5,400)	(13,300)	(41)
Ischemic heart disease	(280)	(1,000)	(2,300)	(22)
Congestive heart failure	(440)	(1,700)	(4,500)	(33)
Stroke	(380)	(1,400)	(3,400)	(36)
Heart attack	(180)	(800)	(2,100)	(35)
Renal failure	(60)	(130)	0	0
Amputation	(10)	(30)	(90)	(63)
Blindness	(20)	(140)	(510)	(40)
Medical expenditures ($ millions)	(69)	(256)	(630)	(9)
Nonmedical economic outcomes ($ millions)	100	349	1,154	4
Household income ($ millions)	106	354	1,145	3
Years of employment	370	2,730	12,610	3
Absenteeism (missed work days)	(29,000)	(28,000)	67,000	1
Absenteeism productivity loss ($ millions)	(5)	(5)	9	1
Supplemental Security Income ($ millions)	(0.4)	(0.3)	(0.5)	0
Mortality	(410)	(2,200)	(6,800)	(20)
Years of life	600	5,500	31,300	4
Total economic benefits ($ millions)	169	604	1,784	
Quality adjusted life years	2,530	9,120	34,720	6

Note: These numbers reflect a representative sample of 100,000 adults with prediabetes who participate in a lifestyle intervention program that achieves 10-year results similar to the Diabetes Prevention Program Outcomes Study. All dollar figures are present values in 2013 dollars, using a 3% discount rate. Numbers might not sum to totals because of rounding. Numbers in parentheses reflect decreases relative to the nonintervention scenario.

guidelines, but that average benefits from a DPP-type lifestyle intervention would be similar to results achieved for an ADA-identified population.

Third, the cumulative benefits of intervention continued to grow over time. Among the ADA-identified population, average gross economic benefits were estimated to be $3,070, $10,500, and $26,800 within 2, 5, and 10 years, respectively.

Screening and detection are precursors to receiving counseling and treatment. USPSTF's lack of recommendation on screening for prediabetes in their 2008 guidelines stems from the paucity of published data on the value of screening and treatment among the general diabetic population.[51] Limited published evidence stems in part from the challenges in using clinical trials as the main source of evidence supporting interventions.[52] Although clinical trials are the gold standard of evidence-based medicine, they often are of insufficient size and duration to quantify outcomes that take years to manifest. In this context, simulation modeling has increased in importance to inform health policy decisions.[53–57]

Yudkin and Montori[58] argue that labeling and treating people with prediabetes are associated with huge social and economic burden. Our work suggests that relatively inexpensive diabetes lifestyle treatment programs can reduce the social and economic burden among this population.

Study Strengths and Limitations

This study used a microsimulation model that incorporates estimates from clinical trials and other sources to track the pathways between a person's characteristics, biometrics, disease risk, onset, mortality, medical expenditures, and workforce participation. Simulation allows for better understanding of the pathways by which reduction in body weight and glycemic levels attributed to lifestyle intervention can prevent or delay onset of

Table 4. Potential Cumulative 10-year Benefits if U.S. Population with Prediabetes Achieved DPPOS Lifestyle Intervention Results

	Total prediabetes population	Meet ADA screening criteria	Meet USPSTF (2008) screening criteria
Estimated national cases with prediabetes in 2010 (millions)	86	37	26
Disease cases prevented, n			
Diabetes	(11,440,000)	(9,480,000)	(6,190,000)
Ischemic heart disease	(1,980,000)	(1,000,000)	(890,000)
Congestive heart failure	(3,870,000)	(1,890,000)	(1,460,000)
Disease incidence prevented, *n*			
Stroke	(2,920,000)	(1,330,000)	(1,070,000)
Heart attack	(1,810,000)	(890,000)	(650,000)
Renal failure	0	(320,000)	(230,000)
Amputation	(80,000)	(70,000)	(50,000)
Blindness	(440,000)	(410,000)	(340,000)
Total U.S. medical expenditures ($ billions)	(539)	(384)	(292)
Medical expenditures per person, $	(6,300) (7,300)[a]	(10,400) (12,000)[a]	(11,200) (12,800)[a]
Total U.S. non-medical benefits ($ billions)	992	607	353
Nonmedical benefits per person, $	11,500 13,700[a]	16,400 19,300[a]	13,500 15,900[a]
Household income ($ billions)	985	603	349
Years of employment (millions)	10.8	7.0	4.2
Absenteeism (millions missed work days)	58	64	44
Productivity ($ billions)	8.0	9.7	6.8
Cost of Supplemental Security Income ($ billions)	(0.4)	(5.9)	(3.5)
Mortality (millions)	(5.8)	(3.0)	(2.5)
Years of life (millions)	26.9	13.5	11.7
Total economic benefits ($ billions)	1,531	991	644
Total economic benefits per person, $	17,800 21,000[a]	26,800 31,300[a]	24,700 28,700[a]
Quality-adjusted life years ($ millions)	25.1 29.9[a]	14.5 17.1[a]	10.6 12.5[a]

Note: All dollar and quality-adjusted life year figures are present values in 2013 dollars and use a 3% discount rate.
[a]Indicates undiscounted estimates. Numbers might not sum to totals because of rounding.
ADA, American Diabetes Association; DPPOS, Diabetes Prevention Program Outcomes Study; USPSTF, U.S. Preventive Services Task Force.

diabetes and sequelae. Simulation also allowed comparisons across different populations.

One limitation is the lack of a single longitudinal data source covering a sufficient time period and of sufficient size to quantify disease onset and the relationship between other patient characteristics. Therefore, data were used from multiple sources, including UKPDS data collected from a population outside the U.S. A second limitation is the use of cross-sectional data for estimating change in BMI and BP associated with aging. Validation activities reported that the model's predictive equations produced outcomes consistent with aggregate published estimates based on longitudinal data. A third limitation is that some predictive equations for the prediabetic population are

based on analyses of a nondiabetic population, which likely understates disease incidence under both the intervention and nonintervention scenarios.

A fourth limitation is that some older data sources were used (e.g., Framingham and UKPDS), and standards of care such as statin use have evolved over time. Data from the Look Action for Health in Diabetes (AHEAD) trial and other studies report that statin use has increased over time and is associated with decreased risk of adverse cardiovascular disease (CVD) events, and that after controlling for cholesterol levels, the impact of body weight loss on CVD outcomes largely disappears.[59–61] The model disease risk equations reflect that absolute probability risk for CVD and other adverse events are generally lower today compared to earlier years.

A fifth limitation is using HbA1c to identify the simulated population and model diabetes onset. Although HbA1c is commonly used for diagnosis, trials often use OGTT owing to sensitivity concerns. Prediabetic adults identified by HbA1c, compared to OGTT, are more likely to be non-Hispanic but have similar age and sex distribution.[62] Prediabetic adults identified by HbA1c, FPG, and OGTT also differ in risk for diabetes and cardiovascular disease—although the association between test type and risk may be partially explained by the other patient characteristics captured in our model.[10] Exploratory analysis using HbA1c and FPG, but not OGTT because of data limitations, suggests that using HbA1c and FPG, rather than HbA1c alone, to identify the simulation population and model diabetes onset increased estimated medical savings from intervention by 4%.

Excess body weight increases risk for various types of cancer, musculoskeletal problems, respiratory problems, and other health issues omitted from this analysis.[63] The estimated benefits of weight loss from lifestyle intervention are conservative with respect to these omitted conditions.

Despite these limitations, validation activities suggest a robust model. Simulated annual transition rates to diabetes absence intervention (5.3%−7.6%) for the population meeting ADA and USPSTF screening criteria are consistent with rates (5%−10%) reported elsewhere.[64] Validation activities found that predicted incidence of cardiovascular events matched well against recent published data.

Sensitivity analysis suggests medical expenditures are most sensitive to HbA1c parameters and assumptions, whereas mortality is most sensitive to CHF assumptions. Excluding HbA1c, varying key modeled parameters by 50% in either direction resulted in maximum deviations from baseline estimates of 4.5%, 10.9%, and 18.8%, respectively, for cumulative 10-year diabetes incidence, medical expenditures, and mortality. This suggests that model results are robust to changes in input assumptions and parameters.

Conclusions

Ninety percent of people with prediabetes are undiagnosed, underscoring the need for a paradigm shift in screening.[65,66] This study highlights the value of treating people with prediabetes. Total simulated economic benefits of lifestyle intervention averaged $26,800 and $24,700, respectively, for people with prediabetes meeting ADA and 2008 USPSTF screening criteria. Published studies suggest that such interventions could be achieved with investments of $\leq$$2,300.[45–47]

Among the estimated 37 million people with undetected prediabetes meeting ADA screening criteria, intervention could potentially prevent 9.5 million diabetes cases with gross national economic benefits of $911 billion over 10 years. By contrast, among 26 million people with undetected prediabetes meeting USPSTF screening criteria, intervention could prevent 6.2 million diabetes cases over 10 years with national economic benefits of $644 billion. These findings illustrate the potential large economic benefits of overall screening and treatment for prediabetes.

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Appendix

Supplementary data

Supplementary data associated with this article can be found at http://dx.doi.org/10.1016/j.amepre.2014.10.003.